

SILVICULTURE OF THE RIVER RED GUM FORESTS OF THE CENTRAL MURRAY FLOOD PLAIN

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ABSTRACT: River red gum, *Eucalyptus camaldulensis* Dehn, occurs in all the mainland States of Australia but its most extensive development is over some 60,000 ha on the flood plain of the Murray River in the region bounded by Tocumwal, Echuca and Deniliquin. Here the forests are usually flooded in winter and spring and form part of a natural flood control reservoir of some 4.1 million Ml capacity. This protects valuable agricultural land further down stream. The forests are also an important source of durable timber, and they have great value for wildlife habitat, recreation and grazing. For these reasons they are not likely to be converted to alternative land use. This paper discusses the silviculture of river red gum in the Barmah State Forest upstream of Echuca in northern Victoria. The red gum type comprises 24,440 ha of this forest.

Natural regeneration of the forest following utilization has been irregular in time and space. This has been due to variable flooding, unfavourable seed beds, inadequate seed supply, and soil drought induced by high evaporative losses and competing vegetation. Research has shown that useful germination occurs on unflooded areas in winter and early spring during periods of regular rainfall. Water temperatures during winter are generally unfavourable for germination on flooded sites, but germination is prolific following flood recession in spring. Soil moisture and seed-bed conditions are the main determinants of seedling establishment, although prolonged flooding limits such establishment even when satisfactory seed-beds have been prepared. It is therefore advantageous to promote rapid seedling growth and so minimize deaths or severe flood injury. Flooding is however largely uncontrollable.

During drought periods red gum seedlings may be destroyed by rabbits, kangaroos, wild horses and cattle. When feed is abundant the adverse effect of all these animals is slight. Extensive grazing of cattle on regeneration areas keeps weeds that are competing with seedlings for moisture in check, and seedling mortality due to soil drought is much less than on ungrazed areas.

The objective of management is to maintain within the Barmah State Forest red gum stands of various stages of development, with associated wildlife and native vegetation, appropriately zoned for timber production, public recreation, wildlife habitat and grazing. Prescriptions have been developed which facilitate the regeneration of utilized forest to satisfy these requirements. This objective can be achieved only if the forest or a substantial part thereof is flooded at least every second year and during suitable seasons. However, in recent years, intensive river regulation has seriously reduced the extent and frequency of winter and spring flooding and caused unseasonal summer flooding in low lying areas. These problems must be overcome if the river red gum forests are to be conserved.

THE RIVER RED GUM FOREST TYPE

This is a general description of the red gum forests on the flood plains below Tocumwal with special reference to Barmah State Forest. Studies of the flooding and regeneration of river red gum reported were carried out in Barmah State Forest between 1961 and 1967 as a project of the Research Branch, Forests Commission, Victoria.

The principal species, *Eucalyptus camaldulensis* Dehn, is found in all the mainland States of Australia but its most extensive development occurs over some 60,000 ha on the flood plain of the Murray River in the region bounded by Tocumwal, Echuca and Deniliquin (Incoll 1946), (Fig. 2). Here mature trees range from less than 21 m to 46 m in height. River red gum forms pure

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stands on the lower ground of the riverain forests, where it receives regular flooding. On higher ground it grows in pure stands or in association with black box, *E. largiflorens* F.v.M.; grey box, *E. microcarpa*; Maiden or yellow box, *E. melliodora* A. Cunn.

The average annual rainfall of 250 — 450 mm in the Victorian riverain zone is too low for vigorous growth, and the forests rely on regular flooding to meet the moisture deficiency.

Jacobs (1955), in describing the growth habits of red gum, noted that seedlings are non-lignotuberos, but a swelling which contains many dormant buds develops near the base of the stem. New shoots may develop from this when seedlings are injured. Cut stumps also coppice vigorously, and in some instances roots form on boles of saplings and young trees below water level when flood waters remain for long periods.

Red gum has weak apical dominance and poor

stem form, especially when open grown (Jacobs 1955). Dense clumps of regeneration occur and in general dominance is asserted slowly, especially on the poorer sites. The form of most saplings in these clumps is good, whereas open grown saplings frequently have a short bole and heavily branched crown.

Red gum is very fire sensitive and even low intensity fire may cause cambial injury. Also it is often attacked by a large variety of insects. In severe cases the entire crown may be destroyed, but in the absence of repeated attack the crowns recover by means of epicormic buds.

Red gum, together with grey box and red ironbark, *Eucalyptus sideroxylon* A. Cunn., are the most valuable heavy construction timbers in southeastern Australia. The timber is renowned for its durability and strength in structural works, being particularly suited in large sizes for wharves, bridges, beams and piles. The main wood

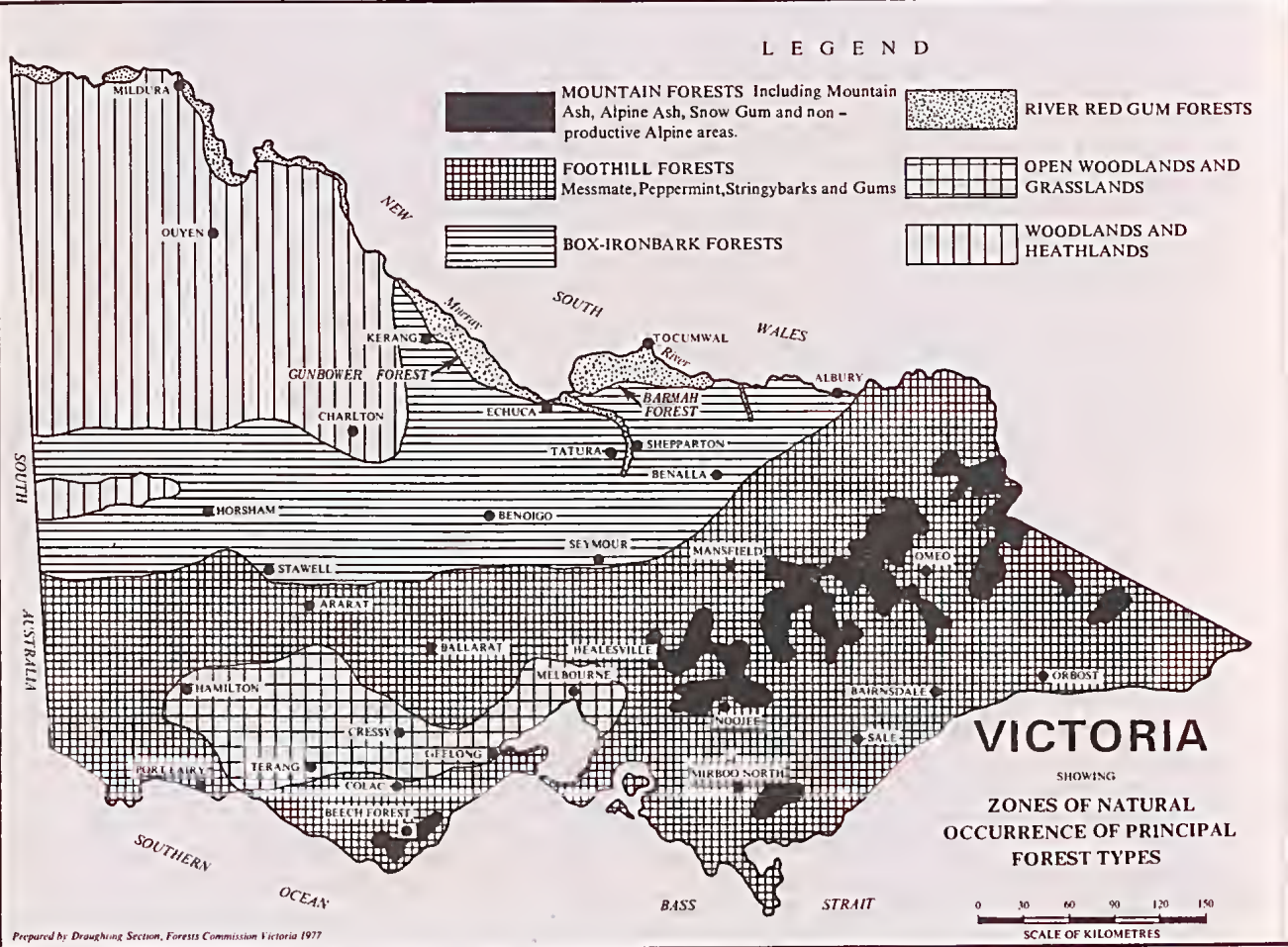


FIG. 1.

procurement operations conducted in river red gum forests at present are sawmilling and sleeper-cutting. The forests also have great value for wildlife habitats, recreation and grazing.

HISTORY OF REGENERATION IN BARMAH FOREST

Selective logging carried out during the past 100 years has resulted in the retention of large numbers of old trees of doubtful value, and defective smaller trees. These cuttings have on some occasions, produced scattered groups of regeneration. In addition to these stands of mixed age there are extensive areas of fairly even age resulting from widespread regeneration in the decade 1870 — 1880. On the basis of records of weather and flooding dating back to about 1860, Jacobs (1955) suggests that this decade constituted the first group of years favouring the extensive establishment of river red gum that occurred between the decline of the aboriginal hunter and his fires, and the increasing presence of sheep, cattle and rabbits.

Since the decade 1870 — 1880 there have been relatively few years during which widespread regeneration has established. Preliminary field observations, supported by flooding, rainfall and flowering records over the last 50 years, have indicated that fairly localized regeneration established in some areas during the periods 1903-04, 1917-18, 1934-35, 1937-38, 1957-58 and 1961-63. Otherwise, however, regeneration has been negligible.

THE PRESENT FOREST

The area under discussion is a flood plain of the Murray River ranging from 94.5 to 109.7 m above sea level (Harrison 1957). Internal elevations differ by only a metre or two with the exception of sand hills which may be up to 12 m above the general level. There are many water courses, swamps and grassy plains, which, together with the lower-lying timbered areas, are periodically flooded in winter and spring. Consequently, logging and other field operations are usually seasonal, often being restricted to six or seven months of the year.

The total area of Barmah State Forest is 28,900 ha. The red gum type comprises 24,440 ha and stands have been classified into three quality classes according to total height of mature trees. Quality I is greater than 30.5 m, Quality II 21 — 30.5 m and Quality III less than 21 m (Campbell 1962). Approximately 34% of the productive area is Quality I and 57% Quality II. The highest quality forest occurs on ground that receives regular

flooding or which is thought to receive water from permanent streams via sandy aquifers.

Grazing has been carried out in the area for approximately 140 years. In the mid-nineteenth century several thousand sheep were grazed annually (Curr 1873) but since the turn of the century beasts have been mainly cattle. At present, this grazing is controlled by a system of agistment. In addition horses, kangaroos and rabbits are of considerable significance in the grazing balance of the forest.

The objective of management of this flood plain forest is to maintain the river red gum ecosystem. This includes the vegetation and wildlife associated with the grassy plains, watercourses, semi-permanent swamps, stands of Black and Yellow Box on higher ground and red gum stands of various stages of development. An important requirement of current management practice is the recognition of specific zones suited to various forest practices and the regeneration of utilized areas as soon as possible. The management objective can be achieved only if the forest or a substantial part thereof is flooded at least every second year during winter and spring. However, in recent years, intensive river regulation has seriously reduced the extent and frequency of such flooding and caused unseasonal summer flooding in low lying areas.

CLIMATE

Meteorological data indicative of conditions in the study area are given in Table 1. Temperature and rainfall were recorded at Echuca and evaporation was measured at Tatura (Fig. 1). Summer and early autumn are relatively hot. Days with a maximum temperature of 38°C or higher may occur 5 to 8 times each year between October and March, while days of 32°C or over occur 30 to 40 times a year. A frost-free period ranges from 7.5 to 8 months. Severe frosts are limited to a period of 8 weeks in June, July and August, and there are usually 6 — 8 each year.

The annual evaporation in the region is approximately 1375 mm. Because of these high evaporation losses and relatively little summer rain, survival and growth of young seedlings during this period depend to a large extent on availability of moisture stored in the sub-soil.

SOILS

Soils of the forest areas are periodically flooded and subjected to water logging, which results in pronounced mottling of sub-soil horizons. Clay is the predominant component of sub-soil horizons and compact layers below the surface hinder pene-

TABLE I
TEMPERATURE, EVAPORATION AND RAINFALL FOR STATIONS IN THE VICINITY
OF BARMAH FOREST.

*Temperature and Rainfall are for Echuca, Evaporation is for Tatura.
Information taken from (Victorian) Central Planning Authority, Goulburn Region 1948 and data supplied by
Tatura Horticultural Research Station.*

Month	Temperature °C. (Base 58 yrs.)					Evaporation (mm) (Base 14 yrs.)	Av. Rainfall (mm) (Base 30 yrs.)
	Mean Max.	Mean Min.	Mean	Highest	Lowest		
January	30.72	15.28	23.00	46.11	4.44	234	21
February	30.77	15.38	23.10	45.00	5.56	184	33
March	27.28	13.17	20.22	41.94	2.94	148	26
April	22.00	9.56	15.83	35.00	-0.56	93	35
May	17.5	6.67	12.05	28.33	-2.22	55	39
June	14.06	5.06	9.56	22.50	-3.33	38	46
July	13.33	4.06	8.72	25.56	-5.00	33	44
August	15.11	5.06	10.06	25.89	-4.44	52	42
September	18.22	6.56	12.39	33.89	-2.22	80	40
October	22.28	8.94	15.56	37.78	-2.78	109	42
November	26.44	11.5	18.94	41.11	-1.11	156	27
December	29.22	13.83	21.56	44.44	1.67	209	30
Yearly mean	22.22	9.61	15.94			Yearly Total 1391	425

tration of water (Davies 1953). Nodules of calcium carbonate occur at various depths below the surface, indicating the depth of penetration of moisture down the profile (Leeper 1952, Butler 1958). The surface soil on areas that receive regular flooding is often silty and hard when dry.

Several profiles were excavated to depths of 1.8 to 2.4 m and although the findings may not apply generally to the forest, some significant features were noted. In some cases the sub-soil was stratified both with respect to composition and texture. Between 1.2 and 1.5 m there was a coarse sand layer several cm thick, and above and below this layer were predominantly clay fractions with a reddish-yellow mottling typical of iron compounds. In some instances there was 'ironstone gravel' in the profile, a feature of soils subject to periodic water-logging (Leeper 1952). Feagan (1947) and Davies (1953) reported similar findings from borings to explore underground water in riverain forests in New South Wales. A typical profile there showed clay layers overlying sand drifts followed by further clay layers.

There was no lateral percolation in those profiles which were uniform throughout. Such profiles excavated to about 1.2 m below the water level of a semi-permanent swamp and only 7.5 m away showed no evidence of lateral percolation after one week. However, there are hundreds of hectares of

high quality forest located on a relatively narrow strip of river frontage which is not normally flooded. It is probable that these stands receive water via lateral percolation from the main stream. Davies (1953) found evidence of lateral percolation associated with stands adjacent to the Murray River. However, most borings indicated that there was no underground water within 9 m of the surface. Where underground water was present it was nearly always confined to layers of sand or gravelly sand. Davies concluded that this water was associated with a prior stream bed under the present forest. How this water is replenished is a matter of speculation, especially as the borings showed that the bulk of surface flooding penetrated only a metre or so through the clay. This was supported by ferric oxide staining in sands above the water table, but beneath heavy clays saturated down to about a metre below the surface, indicating that little downward passage of water had occurred beyond the saturated zone.

Extensive cracking of the surface soil is typical of most locations in the forest. Cracking commences with the onset of rapid drying conditions, and, by the end of summer, cracks of more than 25 mm in width have been traced to depths of 2 m. As little as 7 mm of summer rain may penetrate via these cracks to depths of more than 1.5 m. This source of soil moisture aids seedling establishment.

Further studies showed that the first one to two metres of soil profile are readily saturated even by floods of short duration. Penetration of water is facilitated by the deep cracks, and the sub-soil reaches field capacity at least to depths of 1.2 to 1.5 m. Even in the absence of flooding, the sub-soil is usually saturated in the young seedling root zone by winter rains, at least to 38 cms depth. However, soil in which moisture is replenished by winter rains commences to dry out again during late winter/early spring. By the time of flood recession in late spring/early summer, soil moisture tension in surface layers on unflooded areas may already be at wilting point and the soil has usually commenced to dry out in depth. This contrasts with the high moisture content of soils in flooded or very recently flooded areas.

GROUND FLORA

Moir grass *Pseudoraphis spinescens* (R.Br.) J. W. Vickery, forms the main ground cover in the forest and is also the dominant species on low-lying treeless plains. On heavy permeable soils on the fringes of the flood plain, needle rush, *Eleocharis acuta*, R.Br., forms the ground cover in low quality stands that are rarely flooded.

A list of some of the more common ground flora is given as Appendix 1, together with notes on their distribution within the forest.

FOREST GRAZING

The first record of organized grazing in Barmah forest dates back to the decade 1841 — 1851. During this period Edmund Curr (1883) a squatter, regularly drove sheep from winter runs in southern Victoria (then called the Port Phillip District) to the luxuriant summer pastures of moira grass that developed after winter/spring flooding. Curr obtained about 200 km² of open, grassy forest, occasionally broken by large patches of reed beds, south of the Murray river in the region of the Moira lakes. The size of Curr's flock of sheep varied from 5,000 — 10,000 head. In most years they were moved to the Moira country in November or December where they remained until frost browned the grass, generally in April. Sheep were then moved south to their winter run.

About 1848¹ the area became a 'Station' and even at this time grazing formed an essential part of the economy of the region. In 1864 a railway was established between Bendigo and Echuca.

¹ The following account was drawn from notes kept by settlers and kindly lent by many local residents, from newspapers and from records of the Forests Department.

Utilization of red gum commenced on a limited scale and from about 1870 steam-powered sawmills were being operated to convert timber from the old, open forest into railway sleepers, paving blocks and other heavy construction timber. For the first time industry was being conducted at a level that would ultimately require the regeneration of the forest. In 1883 the first mention of rabbits was recorded on Stations² north of the Murray and no doubt they existed in the Moira region. In 1892 the Stations began serious attempts to eradicate the rabbit and since that time a constant campaign has been waged against the pest.

By about 1885, grazing of sheep in Barmah forest (known as the Barmah Common) gradually gave over to cattle and some horses. Local farm horses were frequently rested after the harvest period on the good summer feed in the forest. The forest was divided into two sections, each under a manager who was nominated by the stock owners to tend their animals on the Common. Gradually Government control was increased and in 1909 the then Forest Department appointed a herdsman to look after the stock.

Forest grazing has continued as an important local industry and allows farmers to carry considerable extra stock over the dry summer and autumn. In recent years about 2,000 head of cattle have had unrestricted grazing over 19,425 ha comprising the central and western sections of Barmah Forest. Usually about two thirds of the cattle are removed from the forest before winter because of the possibility of flooding reducing the area available for grazing.

As well as cattle, several mobs of wild horses roam the agistment area. These are the progeny of some of the former work horses and so far they have defied many attempts to remove all of them from the forest.

FLOODING IN RIVER RED GUM FORESTS

THE FLOOD REGIME OF THE MURRAY RIVER

It is desirable to have some understanding of the Murray River system as a whole, as background to discussing flooding in the region within the triangle formed by Tocumwal, Echuca and Deniliquin (Fig. 2), where the river red gum forest type reaches its highest development.

The Murrumbidgee and Darling Rivers are the main tributaries of the Murray River in a catchment which occupies 107 million ha, covering approximately half of Victoria, three quarters of

² Notes taken on Tulla Station west of Deniliquin (Anon).



FIG. 2 — Flooding of the Murray River below Tocumwal showing existing levee banks (heavy black underlines) and flooded areas in 1956. (Courtesy of the River Murray Commission.)

New South Wales, one sixth of Queensland and, overall, about one seventh of the Australian continent (Ronalds 1950), (Fig. 3). Darling River catchments are principally located in Queensland and northern New South Wales where rainfall is generally due to summer monsoonal depressions. In contrast, Murray catchments above the Darling rely on winter precipitation for run-off. For this reason major floods in the two river systems rarely coincide, more especially as years of sustained high flow in the Darling system are mixed with very severe droughts. On occasions when peak floods do coincide, up to 607,000 ha are inundated in New South Wales and 101,000 ha in Victoria (Fig. 2). However, the flood mitigating capacity is not in proportion to these surface areas, the mean depth in Victoria being estimated at 1.13 m compared with

0.51 m in New South Wales (Harrison 1957). The total capacity of the natural flood control reservoir is approximately 4.1 million Ml. Victoria contributes about 1.1 million Ml which, in relation to the mean depth, represents approximately 13% of the total land area inundated and 25% of the total holding capacity for the region.

Floods in the region under discussion may occur at two periods of the year: from May to August from winter rains, and from September to November from spring rains and melting snow. Except in drought years at least minor flooding occurs in spring, whereas winter floods occur only in wet winters. Approximately 28,328 ha of Barmah Forest are inundated by overflows from the Murray River when the river height at Tocumwal approaches the critical flood stage of

6.1 m. This represents 30% of the land area inundated in the Victorian zone, and in relation to the mean depth, some 8% of the total holding capacity for the whole region.

PHYSIOGRAPHY OF THE MAIN FLOOD BASIN

Below Tocumwal the western flowing Murray River between Deniliquin and Echuca was diverted south by the action of the Cadell Tilt Block, a ridge of land uplifted about 9 m. This block diverted the river south across the slope of the country to the limit of the faulting, where it again flows west after its junction with the Goulburn River. In low lying areas east of the Tilt Block the river developed a great number of anabranches and effluents, those on the east and south returning to the main stream in a relatively short distance and those to the west

and north flowing into the Edward River offtake, returning to the main stream via the Edward and Wakool Rivers some 480 km westwards (Harrison, 1957), (Fig. 2). The significant feature is that overflows to Barmah Forest are much less important as far as wastage of potential irrigation water is concerned, as they soon return to the main stream near Barmah.

CRITERIA FOR FOREST FLOODING

The River Murray Commission and Water Conservation and Irrigation Commission, N.S.W. have provided data on stream flow for the Murray River at Tocumwal and, together with the State Rivers and Water Supply Commission, Victoria, have also provided data on diversion of Murray waters for irrigation in the Murray Basin. Stream

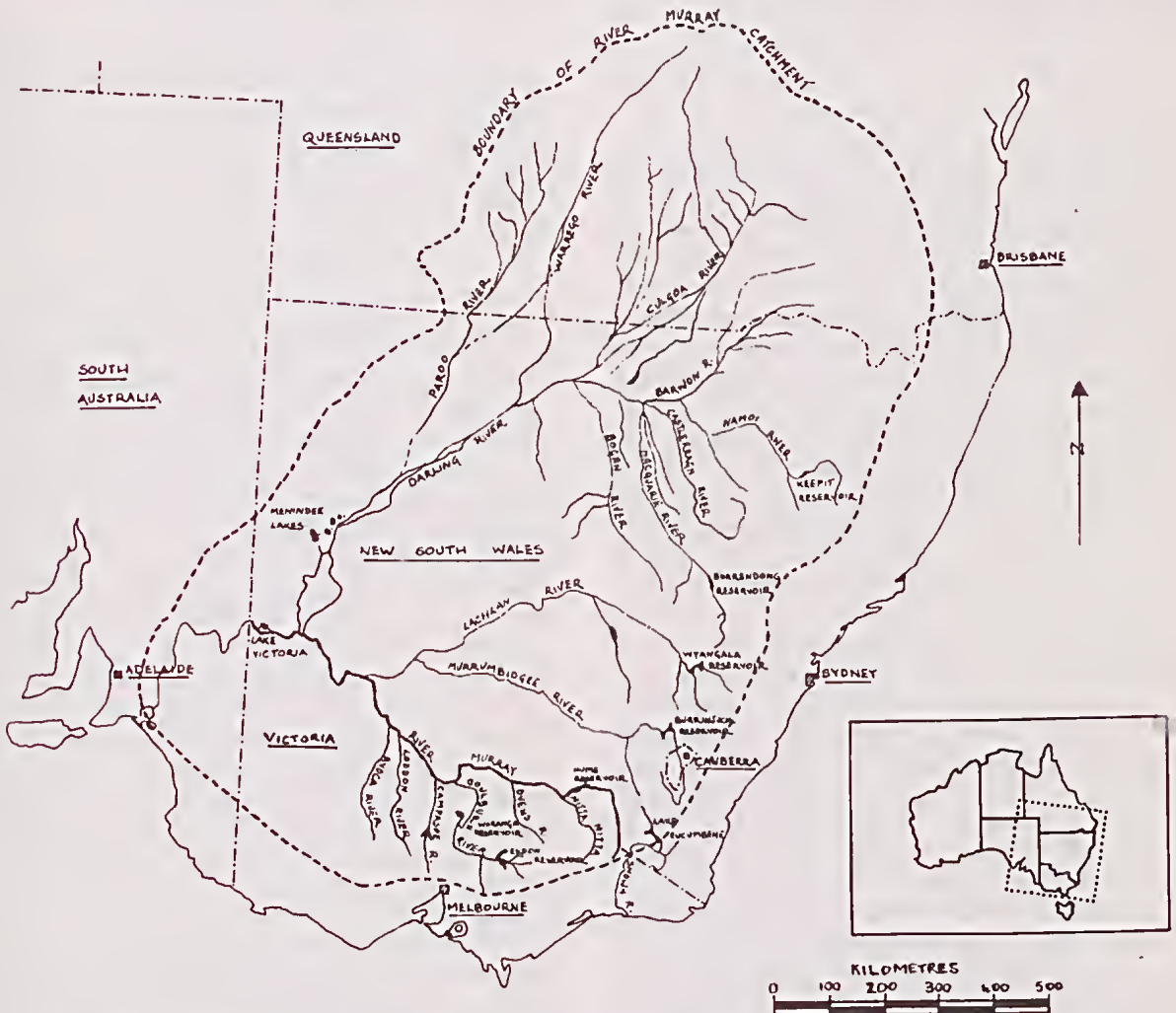


FIG. 3 — Catchment area of Murray River and tributaries. Catchment area 1,072,000 km².
(Courtesy of the River Murray Commission.)

flow profiles showing the height of the Murray River at Tocumwal from May to December between 1886 and 1894, and profiles showing average monthly discharges in Ml per day at Tocumwal from May to December over the period 1895 — 1976 are set out in Appendix 2.

Examination of stream flow data and intensive investigations into forest flooding during 1961 — 1966 indicated that a flow of about 24,500 Ml (3.95 m) must be sustained at Tocumwal for four weeks to flood Barmah Forest (Dexter 1970). Gaugings at Tocumwal were chosen because of the availability of long term records and because there were no effluents or tributaries along the Murray between Tocumwal and forests on this section of the flood plain. Floods capable of inundating the whole of the productive forest area (24,440 ha) regardless of depth and duration were considered to provide an adequate watering.

EFFECT OF RIVER REGULATION ON FOREST FLOODING

Irrigation in the Murray Basin is dependent on water stored in Lake Hume (Fig. 3), which has a capacity of 3,083,705 Ml. A diversion weir at Yarrawonga, 233 river km below Hume Reservoir facilitates the distribution of water to irrigation schemes in the region.

Intensive development of irrigation schemes in the Murray Basin, particularly since 1934, has required a substantial increase in summer stream flow. Long term recordings taken at Tocumwal (State Rivers and Water Supply Commission) show that stream flow, for the months of December to May inclusive, has been increased by the release of stored water from about 20% of the average annual flow for 1895 — 1933, that is, before intensive river regulation for irrigation affected the natural flow, to about 30% for 1934 — 76.

The higher river levels in summer and autumn increased the volume of water entering Barmah Forest via effluents. This increased flow, together with periods of natural flooding led to some lower-lying areas of forest being more or less constantly inundated. These conditions inhibited the establishment of regeneration on these areas, killed some mature red gum stands, and caused deterioration of other stands over hundreds of hectares. Regulators were installed on major effluents between 1939 and 1959 to exclude water from forest areas during the irrigation season. The operation of regulators, which is under the direction of the River Murray Commission, is designed to exclude water from entering the forest except when an over-flow of the natural banks could occur. The volume of water

released from the main stream is the minimum required to keep river flow within the natural banks.

Water is naturally excluded from regulated effluents along river banks bordering the flood plain forests until stream flow exceeds about 6,000 Ml per day at Tocumwal, and may be excluded at the discretion of irrigating authorities until the flow exceeds about 11,000 Ml per day. At this stage water is declared surplus and regulated effluents are usually opened to prevent over-topping of the natural banks along the flood plain and to minimise bank erosion. When sustained flows exceed about 18,000 Ml per day, control by regulated effluents is lost in both Victoria and New South Wales. Consequently, banks bordering the flood plain are overtopped and forest areas function as a natural flood control reservoir.

For several years some summer flows have exceeded 11,000 Ml per day but the regulators have been kept closed to avoid substantial losses of water for irrigation projects downstream. This situation, coupled with the cancellation of planned diversions of water due to local summer rain, has caused serious unseasonal flooding in some low lying areas of forest.

By arrangement with the River Murray Commission, regulated effluents are usually opened during winter months after Lake Victoria (Fig. 3) reaches near-full capacity. Flows less than 11,000 Ml per day are included because there are no further storages downstream to collect surplus winter flow. Lake Victoria was near full capacity when surplus water passed down the Murray River during the winters of 1961, 1962, 1963 and 1964 (Appendix 3). However, it did not reach full capacity by spring 1967 and regulators were kept closed. Data in Appendix 3 show that water could have been almost completely excluded from Barmah Forest during 1961-3 if regulators had been kept closed below a sustained flow of 11,000 Ml per day. With greater demands for water to satisfy the agricultural and urban requirements in the Murray Valley in Victoria, New South Wales, and in South Australia and the greater regulatory capacity afforded by the construction of Dartmouth Dam, it is likely that this situation will occur more frequently unless storages are filled early in the year.

Further to these effects, the regularity with which the whole of Barmah is flooded has declined with the advent of intensive river regulation. Based on the criteria that a flow of approximately 24,500 Ml must be sustained at Tocumwal for about four weeks to flood Barmah Forest adequately, the data

given in Appendix 2 show that the forest was watered in 40 out of 48 years between 1886 and 1933, the period before Hume Reservoir affected the natural flow. Since then the forest has been watered in only 26 out of 43 years. However, stream flow profiles illustrating estimated natural flows show that between 1934 and 1976 an adequate watering would have occurred on seven additional occasions, namely 1937, 1941, 1959, 1962, 1963, 1965 and 1968, if stream flow had not been intensively regulated via Hume Reservoir. Information on rainfall drawn from Hunt (1911), Watt (1937), and the Commonwealth Bureau of Meteorology records for the Murray River catchments above Tocumwal indicate that the decline in flooding has not been due to consistently low rainfall in the catchments. In fact it now appears likely that a full flooding will occur only in years when winter/spring rainfall is well above average. Furthermore, when floods do occur drainage of the low and middle level forests is sometimes delayed, water receding in summer rather than spring. This is because the Murray River below Tocumwal is more frequently above bankfull capacity later in the year compared to the pattern prior to regulation. It will be shown in later sections that summer flood recession may be harmful to red gum establishment.

THE PROBLEM OF REGENERATION

Following the 1944/45 drought there was a period of eight consecutive years when the forest was regularly flooded and seasons were thought to be generally conducive to widespread seedling establishment. However, little worthwhile regeneration was observed to survive beyond the first year. (For. Comm. Vic. 1961). By 1951 concern by the Forests Commission over the lack of regeneration led to the closure to cattle grazing of 6,475 ha in the eastern section of the forest. In addition, local officers established a series of plots, both fenced and unfenced, in the central and western sections and regular observations were carried out to follow the progress of regeneration. By 1960 it was apparent that few seedlings were becoming established in any of the wide variety of locations (For. Comm. Vic. 1961). The situation obviously required a more detailed study to examine all aspects of the regeneration problem.

Valuable leads into the problem were given by Jacobs (1955) who suggested that regeneration of these flood plain forests may be complex and that special conditions may be necessary to secure seedling establishment. Jacobs, over many years, identified several factors that could be responsible

for the great variation in the success of regeneration. He considered that the problem was one of establishment and not of germination and supported this by noting such features as the copious amount of seed produced, the probability, because of periodic flooding, of fewer seed-robbing insects on the forest floor, and the many germinates that regularly appeared when moisture conditions were suitable. However, Jacobs found that few of these seedlings survived, probably because they were very sensitive to both drought and excessive flooding in the first two years. In relation to these factors the level and duration of flooding, which may vary markedly from year to year, can greatly influence the success of regeneration. Jacobs also noted that intensive grazing of seedlings, which can be eaten by rabbits, sheep, cattle and horses, can limit regeneration. Other factors suggested as being deleterious included the influence of bad local seasons and the dominance of veteran trees over many areas.

In 1961, cut-over sections of Barmah Forest were surveyed to assess stocking of regeneration and to appraise characteristics of site and environment that may influence survival and growth of regeneration. Extensive surveys showed that there was usually a prolific strike of seedlings throughout the forest in winter and spring following abundant seed-fall in the preceding summer and autumn. In most instances however, few of these seedlings persisted through summer. Intensive regeneration surveys of cut-over areas showed that usually less than 25% of milacre quadrats were stocked. However, it was notable that quadrats with at least half their area either as disturbed soil or ash bed were much more frequently stocked than quadrats with undisturbed surfaces.

In fact, the surveys indicated that sites favouring establishment of seedlings in average seasons were mainly disturbed, bare, or burnt areas at least 20 m distant from an overstorey tree. In some cases regeneration was confined within definite narrow elevational limits. Established seedlings had a very 'clumped' distribution and frequently occurred in dense thickets. This type of distribution may have been induced by the very specific site factors required for regeneration to establish. In addition, seed source on some areas surveyed was poorly distributed and inadequate.

A provisional standard of acceptable stocking of regeneration has been set at 50% by stocked milacres. Several factors have influenced the choice of such a high stocking standard for river red gum. A relatively dense stand is needed to produce trees with clean, straight boles. Open-grown trees have

short boles and are heavily branched. Fairly dense stocking in the sapling stage is also desirable because at no stage are the eucalypt saplings in competition with associated vegetation that could prevent development of strong laterals. The high frequency of poor form in sapling stands requires that crop trees be selected from a large initial population. In addition, saplings in well-stocked stands are much less susceptible to damage by animals than are open-grown saplings.

The surveys also indicated that the following factors may influence the establishment of a satisfactory density and distribution of regeneration:

1. Seed supply.
2. Incidence of flooding.
3. The time of flood recession, which depends to some extent on whether recession is by drainage or by evaporation, and on the elevation of the areas.
4. Seed bed type.
5. Availability of moisture in the sub-soil.
6. Distribution of summer rainfall.
7. Insects, domestic and other animals.
8. Duration and depth of flooding in the season following germination.

Studies of these factors have been previously described by Dexter (1967) and only a brief summary of the main findings is presented below.

REGENERATION OF RIVER RED GUM

Flowering and Seed Fall: River red gum flowers in most years from late spring to mid-summer but the intensity of flowering varies widely and unpredictably from year to year. About 45% of flowers through the full range from heavy to light flowerings fail to mature. This feature, together with the possibility of very high losses of seed to insects means that natural seed supply is sometimes insufficient for the regular establishment of seedlings.

Seed fall occurs throughout the year commencing about nine months after flowering ends. Free seed fall is least during winter and greatest in spring and summer. High seed fall in spring may have adaptive significance as floods usually recede during this period.

Germination and Seedling Mortality: Useful germination appears on unflooded areas only in winter and early spring and then only in those years when there are significant wet periods. On flooded areas water temperatures during winter are unfavourable for germination, but germination is prolific following flood recession in spring and early summer.

In non-flood years lethal cold temperatures may kill up to 25% of cotyledon-stage germinates

growing in exposed situations, whereas germinates protected by surface cover may sustain less than 10% losses. Seedlings that survive the main frosty period are usually sufficiently advanced to withstand high soil surface temperatures. However, in drought years growth is slow and many cotyledon-stage germinates are killed through their hypocotyls being girdled by temperatures exceeding 65°C at the soil/air junction. Most deaths occur on ash bed and in grass where lethal high temperatures occur early in the growing season. In the absence of a suitable flood regime, soil drought is one of the major causes of seedling mortality. Unless seedlings are fast grown, as for example on ash bed and cultivated seed beds, or summer rains are well above average, soil drought may account for up to 94% loss of seedlings less than twelve months old.

Prolonged flooding is also a major cause of seedling deaths. When flooding is prolonged, seed is either destroyed or young germinates are killed by the hot conditions that usually prevail at the time of late flood recession (mid-summer). Flooding, particularly complete immersion for several months, is lethal to most seedlings less than 25 cm in height. Varying proportions ranging up to 95% of seedlings 50 to 60 cm in height may survive from four to six months inundation depending on the period of total and partial immersion. If flood recession is quick there are few additional deaths, but if recession is slow many of the partially immersed seedlings die. With respect to relatively short term flooding, seedlings can survive up to 14 weeks inundation, including a few weeks of complete immersion, with little ill effect. The only damage sustained is the shedding of the lower leaves of small seedlings.

Growth Habits and Survival of Seedlings: Young seedlings have characteristics which assist them in surviving periods of moisture stress in spring and summer. Woody stemmed seedlings at least up to 15 cm in height may shed all their leaves in times of prolonged moisture stress and recover via shoots from axillary buds when moisture becomes available again.

All classes of seedlings beyond the cotyledon-stage and at least up to 23 cm in height have an average root length/shoot length ratio of 4.5. Root systems of well developed seedlings therefore extend deep into the sub-soil where moisture is generally available for survival over summer.

Rapid early growth associated with receptive seed beds is important for seedling survival and establishment. For example, at age three to five months the average height of seedlings on deep ash bed and well cultivated surfaces is four to eight

times that of seedlings on hard, bare surfaces and grassed sites. On receptive seed beds, the root systems of these seedlings develop down to 20 — 50 cm below ground surface, that is, four to eight times the depth of root development on unreceptive seed beds. Moisture is usually available for seedling survival under receptive seed beds over summer, even in the absence of previous winter/spring flooding. Furthermore, initial rapid growth aids establishment, and big seedlings are least likely to be destroyed or badly injured by a period of flooding in the year following germination.

Influence of Trees and Ground Flora on Seedling Establishment: In the absence of flooding, winter rains can provide sufficient soil moisture for the establishment of river red gum seedlings provided ground vegetation and/or overstorey trees are not competing for this moisture. On sites colonized with annuals and perennial grasses, moisture is rapidly depleted early in the growing season. In the absence of competition seedling survival is some 20 to 30 times greater.

Similarly, the availability of moisture for seedling survival is greatly reduced within the zone of influence of trees. The zone appears to increase with lowering of site quality and may extend for up to 40 m around a mature tree. The severity and duration of moisture stress imposed by these agencies depends on the prevailing seasonal conditions and flooding.

Grazing: During prolonged dry periods when feed is scarce, heavy browsing by rabbits and kangaroos will destroy the majority of young red gum seedlings. Serious damage is usually localized to a few hectares. When feed is abundant, the effect of these animals is slight. Cattle and horses have a similar potential to destroy young seedlings but this rarely occurs under the present system of grazing under agistment in Barmah Forest. Likewise, under this system, grazing of cattle on regeneration areas is not detrimental to seedling establishment. In fact, cattle grazing on weeds, which would otherwise be in strong competition with young seedlings for moisture, results in seedling stocking remaining at a satisfactory level. Without the control of weed competition, seedling stocking may fall below requirements for effective regeneration.

SILVICULTURAL TECHNIQUES

Studies of the main requirements for seedling establishment have led to the development of procedures which greatly improve the chances of obtaining adequate regeneration. These are based on effectively distributing seed on to receptive seed beds. Seed beds are made receptive by removing

grass and other vegetation, preparing the ground surface by slash burning and cultivation, and poisoning non-merchantable trees. Seed is provided by inducing seed fall from an adequate proportion of crop trees or by direct seeding. There are two main silvicultural techniques that are variously applicable to regenerating river red gum.

(1) PROCEDURES BASED ON DIRECT SEEDING

Clear felling followed by aerial seeding is the cheapest and most flexible technique. The major costs involved are in seed bed preparation, poisoning non-merchantable trees, collecting seed, and in aerial seeding. None of these operations is expensive. Sowing rates and time of sowing are determined on the bases of expected flooding and seed bed quality.

(2) PROCEDURES BASED ON NATURAL SEED SUPPLY

These procedures involve preparation of seed beds and inducement of seed fall during summer and autumn, then utilization of merchantable, and poisoning of non-merchantable trees. The required timing of each phase to suit such factors as seed maturation, and seed fall and germination reduces flexibility and increases costs. One of these techniques, clear felling in one stage, is applicable to lightly stocked areas that have been previously heavily cut-over. The second, clear felling in two stages, is applicable to areas which have been less heavily cut-over and on which most of the crop can be utilized.

The choice of the regenerative procedure will depend on the particular characteristics of the stand to be utilized: for example, availability of natural seed source, volume of merchantable material, size and location of coupe. Other constraints to be considered are the shortage of labour and the unpredictable seasons associated with red gum forestry. With the procedures tested, experience has indicated that two-stage cut techniques can become unmanageable, especially on coupes exceeding 20 ha, because of difficulties in adhering to the required timing of each phase of the operation. On the other hand, operations based on clear felling and direct seeding are much more flexible. Field trials of these techniques have regularly provided satisfactory stockings of regeneration.

MANAGEMENT

The objective of management of Barmah State Forest is to maintain the river red gum ecosystem with its variety of forest conditions, associated wildlife and native vegetation, so that it is capable of sustained use for timber production, public

recreation, wildlife habitat and grazing. An important requirement of current management practice is the recognition of specific zones suited to these various forest practices, and the regeneration of utilized areas as soon as possible. The objective can be achieved only if the forest, or a substantial part thereof, is flooded at least every second year and at suitable times of the year. However, regulation of river flows in the Murray catchment above Tocumwal is causing problems. It is reducing the frequency and extent of winter and spring flooding on the low-lying middle level areas of the Barmah Forest, and mostly eliminating floods on the higher red gum areas. Furthermore, when floods do occur, drainage of the low and middle level forests is being seriously delayed, water receding in summer rather than in spring. This is because the Murray River below Tocumwal is more frequently above bankfull capacity later in the year compared to the pattern prior to regulation. High levels in the river when water is being delivered from storages are also causing summer floodings. These occur at short notice when there are sudden cancellations in diversions for irrigation water.

These changes are having ill effects on the forest. The red gum in the low and middle levels needs winter or spring flooding. Without water at that time it is unable to make vigorous growth and becomes subject to serious attack by the seedling gum moth. Late drainage causes serious losses of crops of young seedlings and saplings, and spillovers from the high summer river levels accentuate the development of wet lands in low areas with death of trees, spread of reed beds and losses of grazing country.

Furthermore, these departures from the natural sequence of flooding also cause changes in waterfowl habitat. Duration and depth of flooding, and more particularly season of flooding, control the regeneration of ground flora which are important to the feeding and nesting requirements of these birds. Consequently, the reduction in the frequency and extent of winter and spring flooding, the late recession of water and unseasonal summer floodings, are factors of great concern.

With the construction of Dartmouth Dam the storage capacity in the Upper Murray has been increased by some 3.7 million ML. The greatly increased regulatory capacity thus provided could further reduce winter flows above bankfull capacity in the central Murray flood plain. It could also seriously aggravate the summer flooding problems if high river flows are maintained for irrigation requirements.

Such problems must be overcome and a suitable

watering regime developed in consultation with regulating authorities if the river red gum forests are to be conserved.

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APPENDIX I

SOME OF THE MORE COMMON GROUND FLORA FOUND IN BARMAH FOREST WITH
NOTES ON THEIR DISTRIBUTION

<i>Botanical Name</i>	<i>Notes</i>
A. Monocotyledons	
<i>Agrostis avenacea</i> J.F. Gmel (Gramineae)	Rarely flooded areas; low site quality.
<i>Anguillaria dioica</i> R.Br (Liliaceae)	Species colonizing cultivated areas subjected to regular flooding.
<i>Bromus macrostachys</i> Desf. (Gramineae)	Rarely flooded areas; low site quality.
<i>Danthonia duttoniana</i> A.B. Cashmore (Gramineae)	Rarely flooded areas; low site quality.
<i>Hordeum hystrix</i> Roth (Gramineae)	Rarely flooded areas; low site quality.
<i>Juncus subsecundus</i> N.A.Wakefield (Juncaceae)	Low swampy areas.
<i>Koeleria phleoides</i> (Vill.) Pers. (Gramineae)	Rarely flooded areas; low site quality.
<i>Lolium perenne</i> L. (Gramineae)	Rarely flooded areas; low site quality.
<i>Phalaris tuberosa</i> var. <i>stenoptera</i> (Hack) Hitchc (Gramineae)	Generally on high ground; rarely flooded.
B. Dicotyledons	
<i>Acacia acinacea</i> Lindl. (Leguminosae)	Box ridges, rarely flooded.
<i>Alternanthera denticulata</i> R.Br. (Amaranthaceae)	Colonizer of bare soil areas and ash beds; site quality 1-3.
<i>Cardamine hirsuta</i> (L) (Cruciferae)	Rarely flooded areas; low site quality.
<i>Centipeda minima</i> (L) A.Br. et Aschers (Compositae)	Unflooded areas or areas subjected to irregular flooding.
<i>Centipeda cunninghamii</i> (D.C.) A. Br. et Aschers (Compositae)	Colonizer of bare soil areas; site quality 1-3.
<i>Cotula bipinnata</i> Thurb (Compositae)	Low site quality (high ground).
<i>Eleocharis acuta</i> R.Br. (Cyperaceae)	Rarely flooded areas; low site quality areas subjected to water logging from winter rains.
<i>Gnaphalium involucreatum</i> Forst (Compositae)	Generally on high ground. Found to colonize high site quality areas during repeated non-flood year.
<i>Inula graveolens</i> (L) Desf. (Compositae)	Species colonizing areas subjected to regular flooding.

<i>Lactuca serriola</i> (L.) (Compositae)	Unflooded or rarely flooded areas.
<i>Ludwigia peploides</i> (Kunth.) P.H.Raven (Onagraceae)	Species colonizing cultivated areas subjected to regular flooding.
<i>Myriophyllum propinquum</i> A.Cunn. (Haloragaceae)	Primarily a large growing chiefly-submerged fresh water aquatic. Persists in a very reduced state on damp soil. Colonizer of bare soil areas use; site quality 1-3.
<i>Oxalis corniculata</i> L. (Oxalidaceae)	Rarely flooded areas; low site quality.
<i>Polygonum aviculare</i> L. (Polygonaceae)	Colonizer of bare soil areas; high site quality in the absence of flooding.
<i>Polygonum hydropiper</i> L. (Polygonaceae)	Species colonizing bare soil areas subjected to regular flooding.
<i>Polygonum minus</i> Huds. (Polygonaceae)	Species colonizing bare soil areas subjected to regular flooding.
<i>Polygonum plebeium</i> R.Br. (Polygonaceae)	Colonizing bare soil areas on high site quality in the absence of flooding.
<i>Solanum esuriale</i> Lindl. (Solanaceae)	Unflooded or rarely flooded areas.
<i>Wahlenbergia fluminalis</i> (J.M.Black) Wimmer ex H. Erchler (Campanulaceae)	Colonizer of bare soil areas, site quality 3.

APPENDIX 2
RIVER MURRAY FLOWS GAUGED AT TOCUMWAL,
MAY-DECEMBER INCLUSIVE, 1886-JUNE 1977

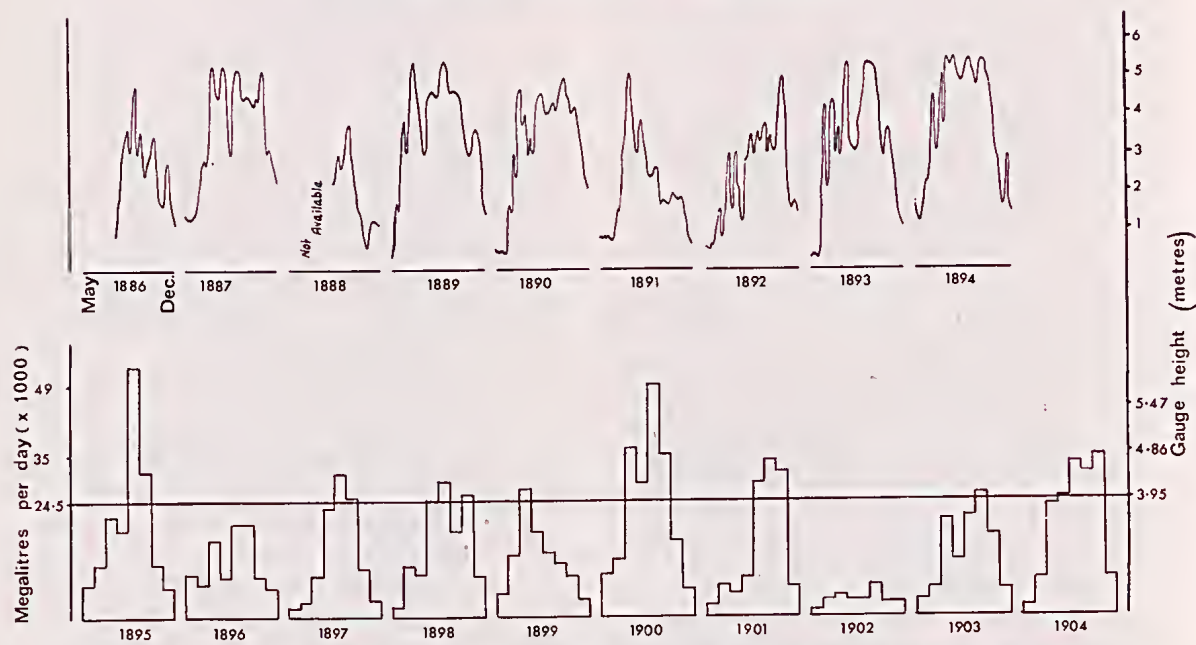


FIG. A2,1 — Flow profile from August 1886 to December 1894, followed by average monthly discharges in Ml per day for the months May to December inclusive. (Covers years 1886-1904.)

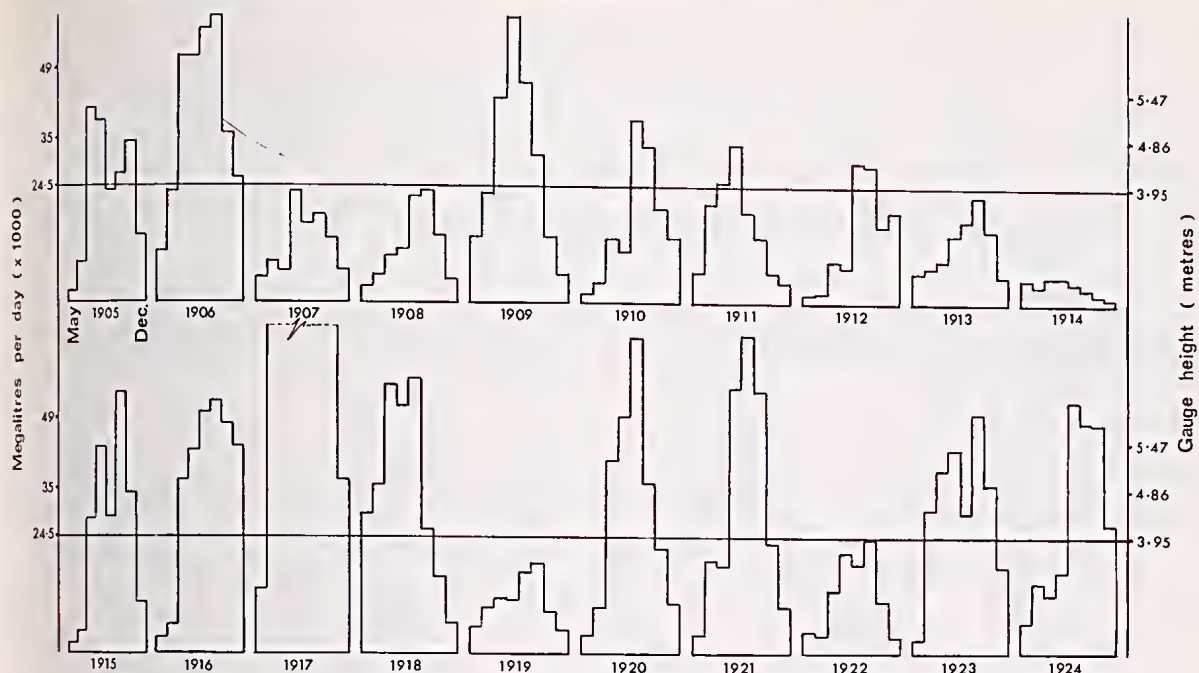


FIG. A2.2 — Average monthly discharges in Ml per day for the months May to December inclusive.

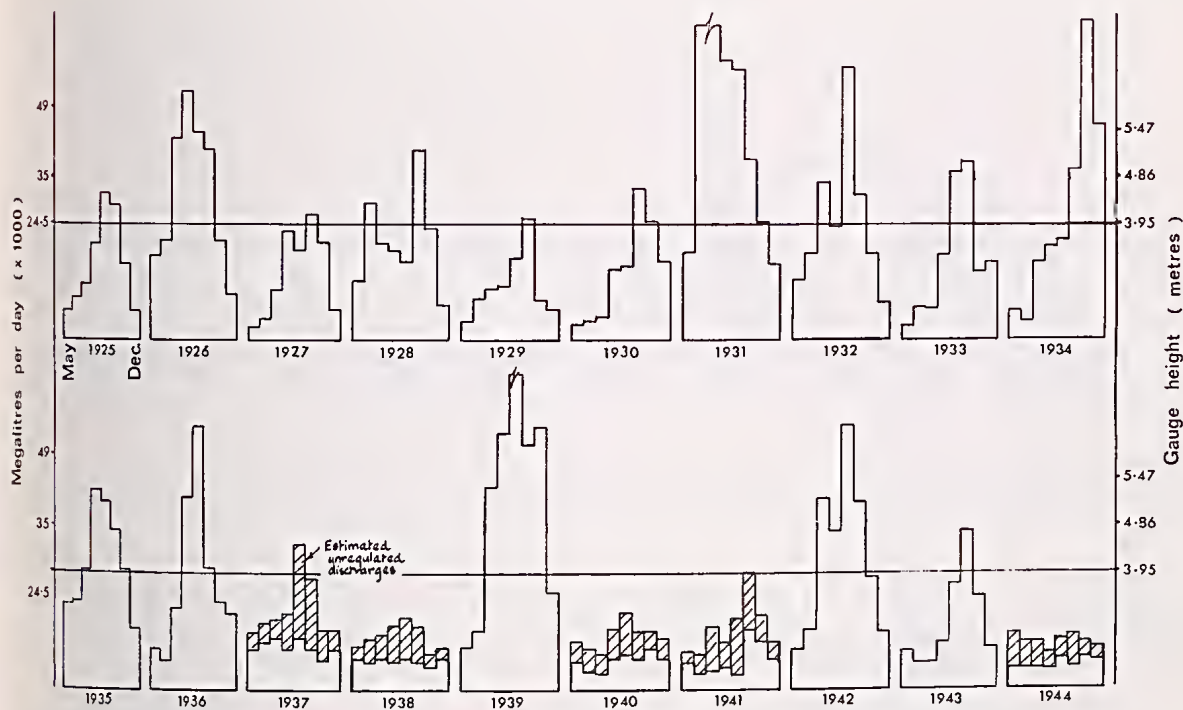


FIG. A2.3 — Average monthly discharges in Ml per day for the months May to December inclusive. From 1934 (Hume Reservoir completed) regulated discharges are shown, but in dry years estimated natural discharges are also shown. (Covers years 1925-1944.)

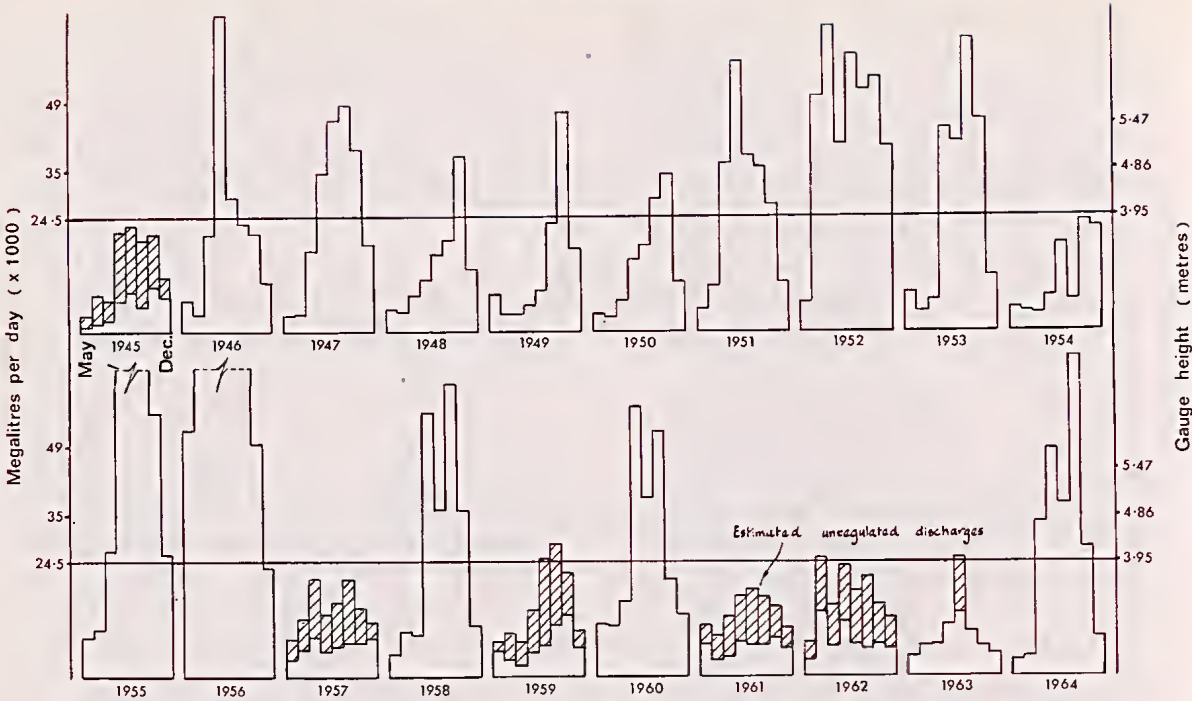


FIG. A2.4 — Regulated monthly discharges in Ml per day for the months May to December inclusive. In dry years estimated natural discharges are also shown. (Covers years 1945-1964.)

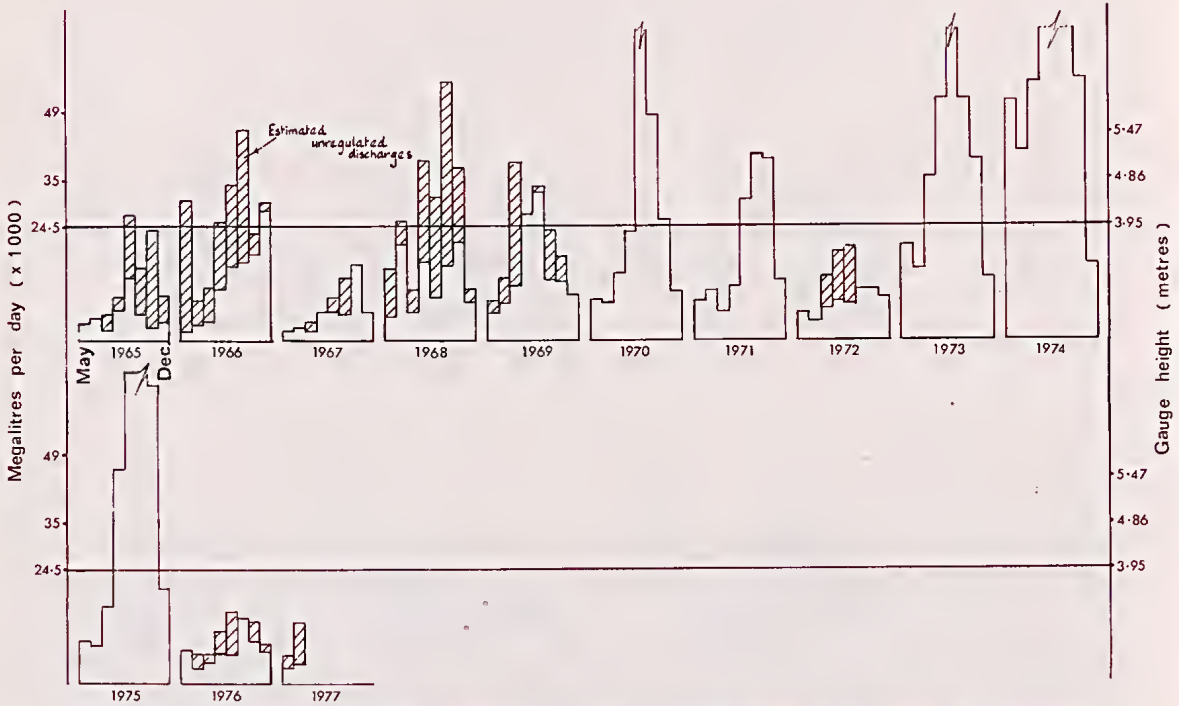


FIG. A2.5 — Regulated monthly discharges in Ml per day for the months May to December inclusive. In dry years estimated natural discharges are also shown. (Covers years 1965-1977.)

APPENDIX 3
EFFECT OF STORAGE CAPACITY IN LAKE VICTORIA AND OF FOREST
REGULATORS ON FLOODING OF BARMAH FOREST

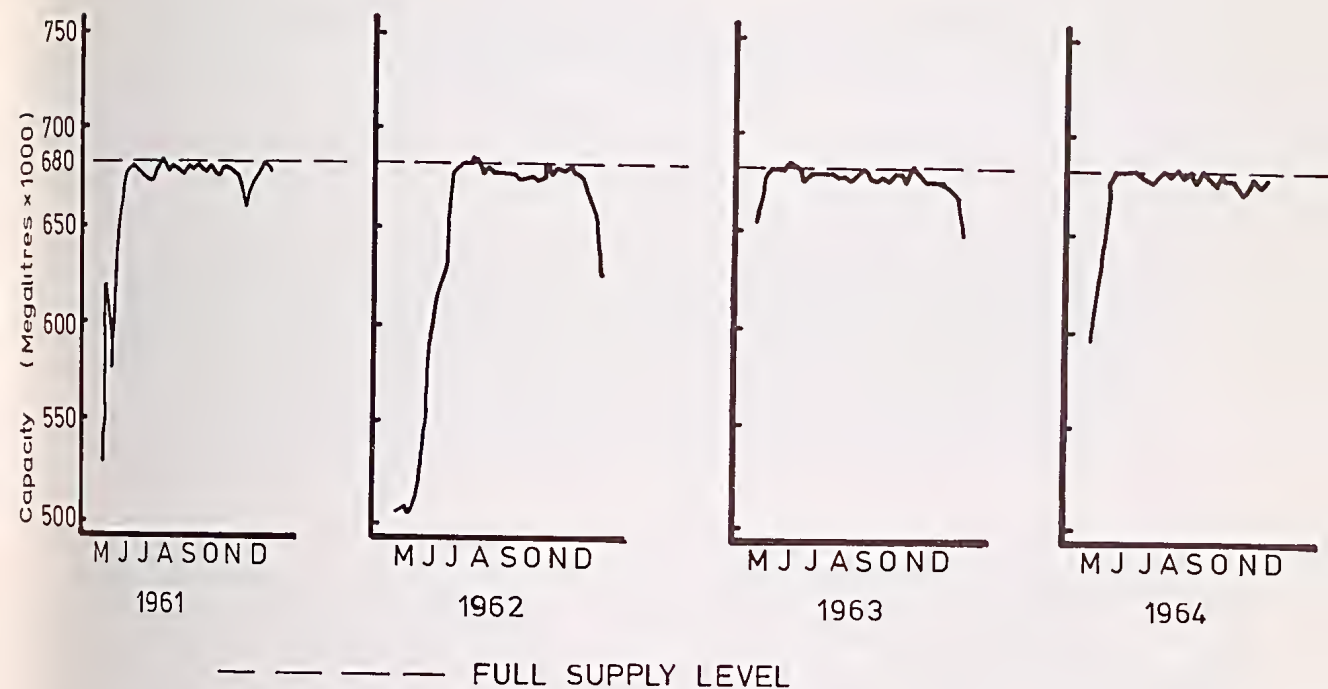


FIG. A3.1 — Storage capacity at Lake Victoria in relation to full supply level for May to December inclusive, 1961 to 1964.

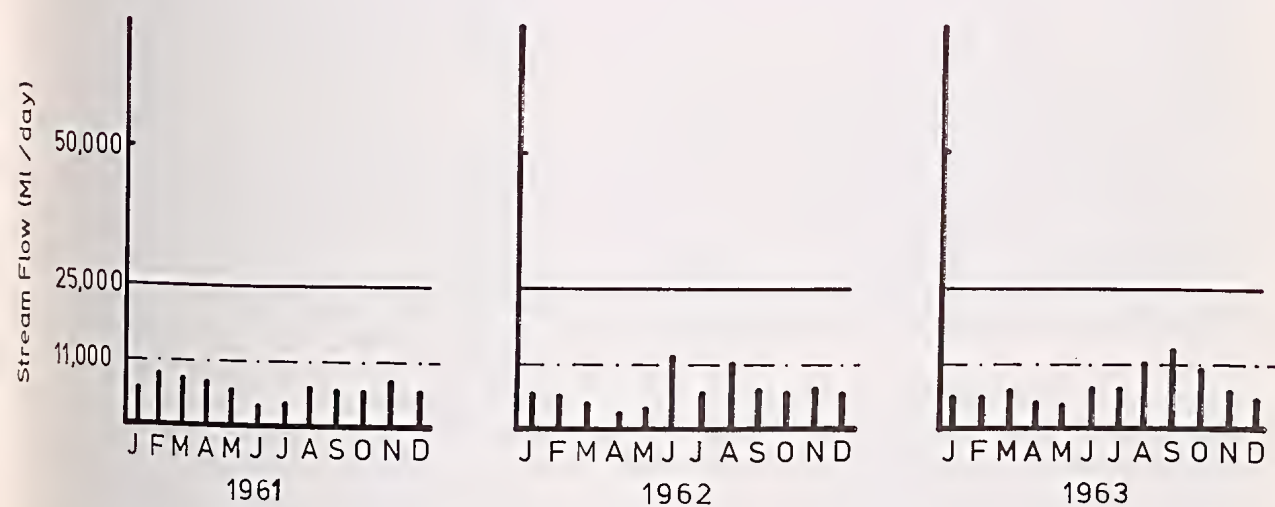


FIG. A3.2 — Stream flow profiles for the Murray River at Tocumwal. Average monthly discharges in Ml/day. January to December inclusive, 1961 to 1963.